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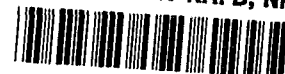
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**EFFECTS OF ANTIWEAR AND
EXTREME-PRESSURE ADDITIVES IN A
SYNTHETIC PARAFFINIC LUBRICANT
ON BALL SPINNING TORQUE**

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16. Abstract Tests were conducted in the NASA spinning-torque apparatus to determine the effect of lubricant additives on the torque of a ball spinning in a nonconforming groove. The base lubricant was a synthetic paraffinic oil to which were added 0.1, 1.0, and 10 volume percent of either an antiwear or EP additive. The additives used were stearic acid, oleic acid, oleyl phosphate, oleyl phosphite, and zinc dithiophosphate. Under the test conditions, elastohydrodynamic lubrication prevailed with no significant surface interaction. The addition of the antiwear or EP additives in several concentrations to the synthetic paraffinic oil did not change the spinning torque over that obtained with the base fluid. The viscoelastic properties of the base fluid were not changed by the additives tested.		
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EFFECTS OF ANTIWEAR AND EXTREME-PRESSURE ADDITIVES IN A SYNTHETIC PARAFFINIC LUBRICANT ON BALL SPINNING TORQUE

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SUMMARY

The NASA spinning torque apparatus was used to conduct tests with SAE 52100 steel 1/2-inch (12.7-mm) diameter balls spun against nonconforming groove specimens with a conformity of 55 percent. The lubricant was a synthetic paraffinic oil to which were added 0.1, 1.0, or 10 volume percent of either an antiwear or extreme-pressure (EP) additive. The additives used were stearic acid, oleic acid, oleyl phosphate, oleyl phosphite, and zinc dithiophosphate. Test conditions included maximum Hertz stresses of 60 000 to 200 000 psi (41×10^7 to 138×10^7 N/m²), a spinning speed of 1000 rpm, and room temperature (no heat added). The spinning torques were measured for each test condition.

Under the test conditions elastohydrodynamic conditions prevailed with no significant surface interaction. The addition of the antiwear or EP additives in various concentrations to the synthetic paraffinic oil did not change the spinning torques over those obtained with the base fluid. The viscoelastic properties of the fluid were not changed by the additives tested.

INTRODUCTION

In bearing and gear applications, where thin film or boundary lubrication conditions may exist, antiwear and extreme-pressure (EP) additives are used in the lubricating fluid. In many gear applications, the addition of antiwear or EP additives to the lubricant can prevent excessive wear of the gear teeth. In a ball bearing, the ball both spins and rolls in an angular-contact raceway. Bearing power loss is due to a number of factors: shearing of the lubricant in the bearing cavity; rubbing of the ball against the cage pocket, rubbing of the cage against one of the raceways, and spinning of the ball in the raceway. Antiwear and EP additives should decrease this power loss by reducing friction in the ball-cage contact and the race-cage contact. In addition, the additives should

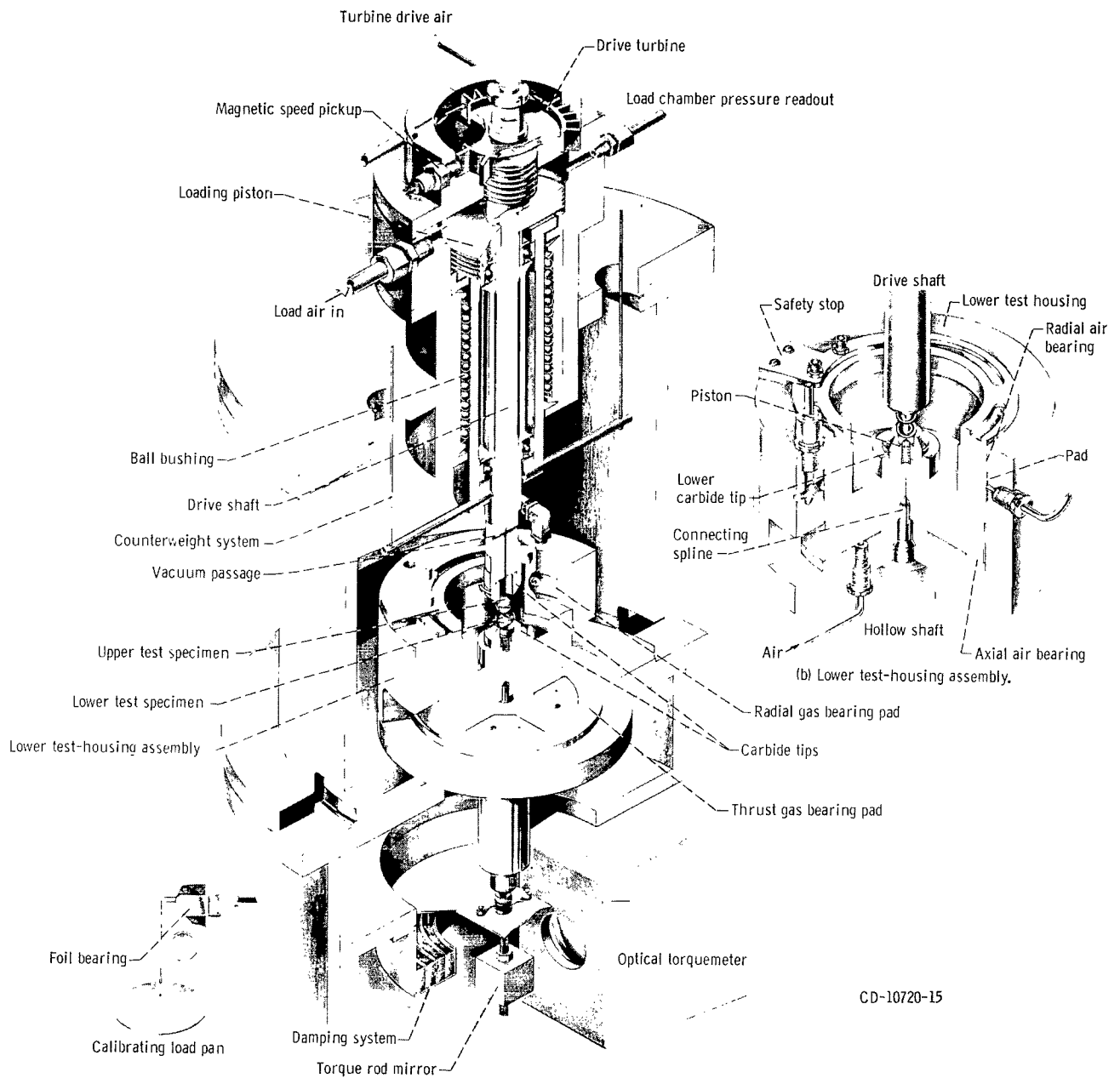
also decrease wear in these sliding contacts. The question remains whether friction is reduced in the ball-race contact.

The addition to the lubricant of certain reactive materials in a sliding condition where boundary lubrication exists will decrease the coefficient of friction over that obtained with a nonreactive lubricant. Additives such as stearic acid and oleic acid on steel form metallic soap films of iron stearate and iron oleate (refs. 1 and 2) that shear easily and reduce sliding friction (refs. 3 to 5). The phosphate additives such as tricresyl phosphate and oleyl phosphate form surface films of ferric phosphate on the surface of steel, causing a reduction of wear and friction under boundary sliding conditions (ref. 6).

Under elastohydrodynamic conditions, a rolling element is separated from a mating surface by a thin lubricant film (ref. 7). This thin film may be the same order of thickness as the boundary film formed by the antiwear or EP additives. Where there is complete separation of the surfaces, antiwear and EP additives should have very little or no effect on wear but may have some effect on friction due to a change in the lubricant shear behavior; that is, a change in the lubricant viscoelastic behavior. This viscoelastic change would cause a change in the EHD film thickness. A decrease in film thickness should result in an increase in measured torque (ref. 8). Where there is significant asperity interaction, an additive of the antiwear or EP type should have some measurable effect on friction and wear.

Analysis (ref. 9) has indicated that, for a ball spinning in a nonconforming groove without rolling, an elastohydrodynamic film can be formed. However, it was not determined whether the film was thick enough to prevent surface interactions. If surface interactions did occur, the values of torque measured should be significantly affected by the presence of an antiwear or EP additive.

The objective of the research reported herein was to determine the effect of several lubricant additives of the EP or antiwear types on the spinning torque caused by a ball spinning without rolling in a nonconforming groove. To accomplish this objective, tests were conducted in the NASA spinning torque apparatus at room temperature with five additives of the EP or antiwear type. These additives were stearic acid, oleic acid, oleyl phosphate, oleyl phosphite, and zinc dithiophosphate. The additives were mixed in a synthetic paraffinic oil in concentrations of 0.1, 1.0, and 10 percent. Test conditions included a ball-groove (race) conformity of 55 percent, a drive speed of 1000 rpm, maximum Hertz stresses from 60 000 to 200 000 psi (41×10^7 to 138×10^7 N/m²) with no heat added. All experimental results were obtained with lubricant from the same batch and specimens from the same heat of material.



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(a) General cutaway view.
Figure 1. - Spinning-torque apparatus.

APPARATUS, SPECIMENS, AND PROCEDURE

Spinning Torque Apparatus

A spinning torque apparatus (see fig. 1) as reported in references 10 and 11 was used for the tests reported herein. The apparatus essentially consists of a turbine drive, a pneumatic load device, an upper and lower test specimen, a lower test-housing assembly incorporating a hydrostatic air-bearing, and a torque-measuring system. In operation, the upper test specimen is pneumatically loaded against the lower test specimen through the drive shaft. As the drive shaft is rotated, the upper test specimen spins in the groove of the lower test specimen. This causes an angular deflection of the lower test-specimen housing. This angular movement is sensed optically by the torque-measuring system and is converted into a torque value. During a test, the torque is continuously recorded on a strip chart.

Specimens

The upper test specimen is a conventional 1/2-inch (12.7-mm) diameter bearing ball made of SAE 52100 steel having a nominal Rockwell C hardness of 61 and a surface

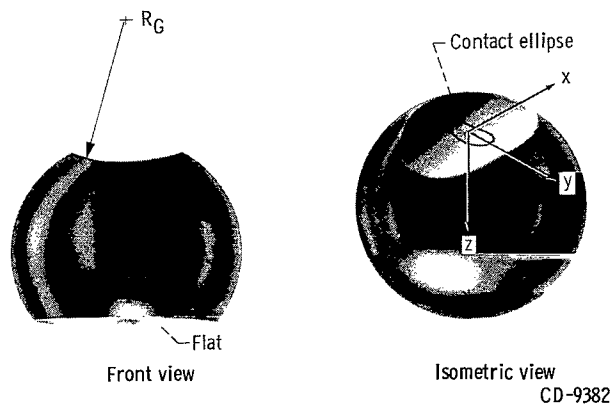


Figure 2. - Lower test specimen.

finish of 2 microinches ($5 \mu\text{cm}$) rms. The lower test specimen (fig. 2) is a 1/2-inch (12.7-mm) diameter ball from the same heat of material as the upper test specimen which is modified by grinding a flat on one side and a cylindrical groove of radius R_g (fig. 2) on the other. The groove simulates the race groove of a bearing. The axis of the groove is parallel to the flat. The groove radius expressed as a percentage of the upper-ball diameter is defined as the ball-race conformity. The specimens used in these tests were ground to ball-race conformities of 55 percent. The surface finish of the cylindrical groove was approximately 2 to 6 microinches (5 to 15 μcm) rms.

Lubricant

The lubricant used for the test was a synthetic paraffinic type with a kinematic viscosity of 448 centistokes at 100° F (311 K) and 43 centistokes at 210° F (372 K). The lubricant was modified for the tests by the addition of 0.1, 1.0, or 10 percent of stearic acid, oleyl phosphate, oleyl phosphite, or zinc dithiophosphate. The stearic acid and oleic acid form iron stearate and iron oleate, respectively, with steel (refs. 1 and 2) which reduce boundary friction by reducing the shear strength of the surface layer (refs. 3 to 5). The oleyl phosphate and oleyl phosphite react with iron to form low shear strength iron phosphate and iron phosphite, respectively. These films also reduce the shear strength of the surface and thus reduce friction (ref. 6). The zinc dithiophosphate does not react with iron but forms a low shear strength boundary film on the surface of the iron thereby reducing friction and wear.

Operating Procedure

Prior to test, the specimens were ultrasonically cleaned in ethyl alcohol and vacuum dried for 24 hours. During a test, the experimental value of spinning torque was determined from a strip chart after a steady-state value of angular deflection was reached. The tests were first run with the nonadditive lubricant. The tests were then consecutively repeated for single additive concentrations of 0.1, 1.0, and 10 percent. The specimens were changed when either the additive concentration or additive type was changed.

Tests were run at room temperature (i. e., no heat added) with maximum Hertz stresses ranging from 60 000 to 200 000 psi (41×10^7 to 138×10^7 N/m²). Spinning speed was 1000 rpm and the contact conformity was 55 percent for all additives used. All experimental results were obtained with lubricant from the same batch and specimens from the same heat of material.

RESULTS AND DISCUSSION

Tests were conducted with SAE 52100 steel 1/2-inch (12.7-mm) diameter balls in the NASA spinning torque apparatus against lower grooved test specimens with a conformity of 55 percent. The resulting torques due to ball spinning were measured. The results were evaluated with respect to the type and amount of additive and the maximum Hertz stress.

The results of the tests with the synthetic paraffinic oil without any additives are shown in figure 3(a) as a function of stress. These results compare with data obtained

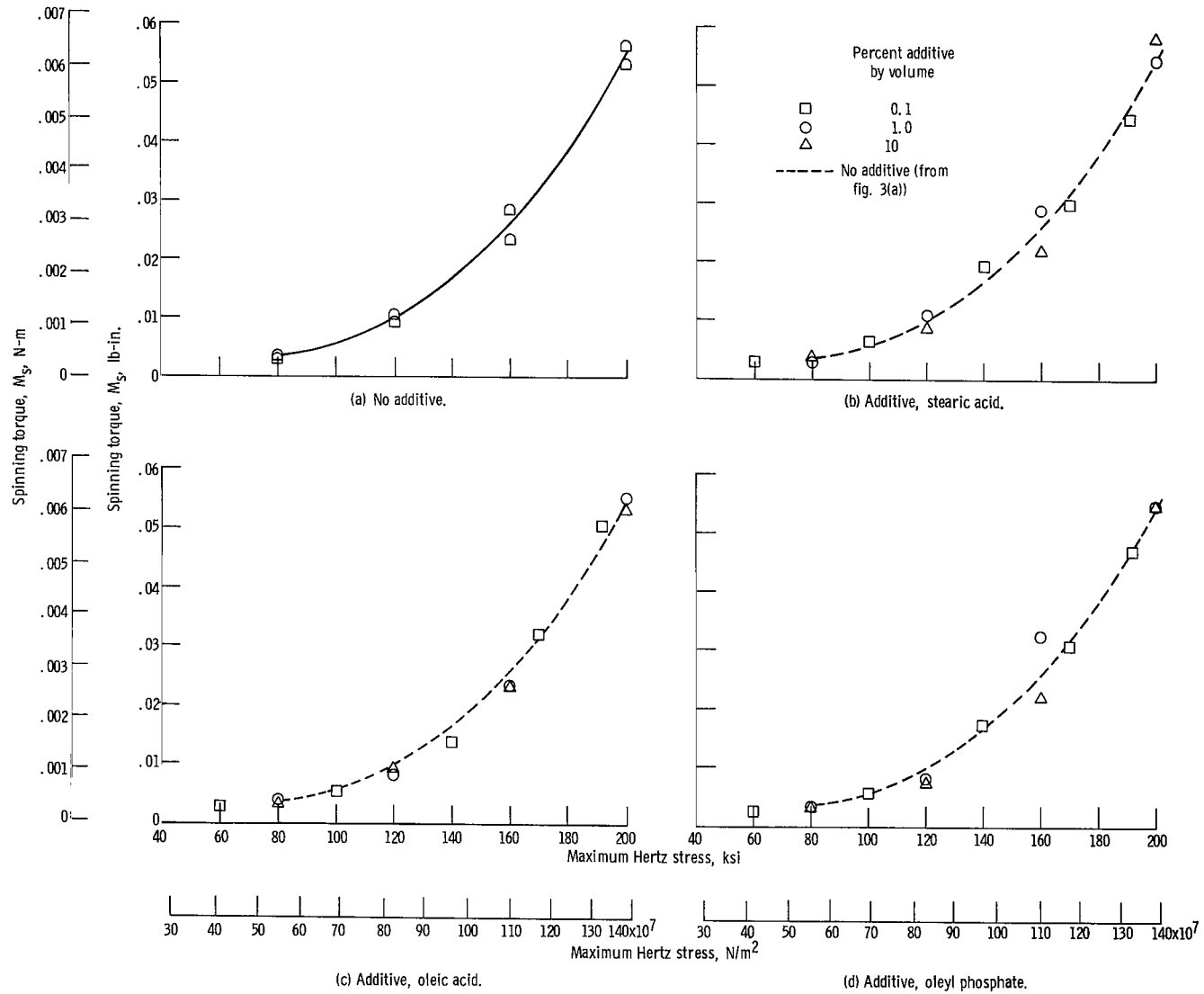


Figure 3. - Spinning torque as function of maximum Hertz stress for synthetic paraffinic lubricant with several additives in varying amounts. Spinning speed, 1000 rpm; conformity, 55-percent; base lubricant, synthetic paraffinic oil; room temperature (no heat added).

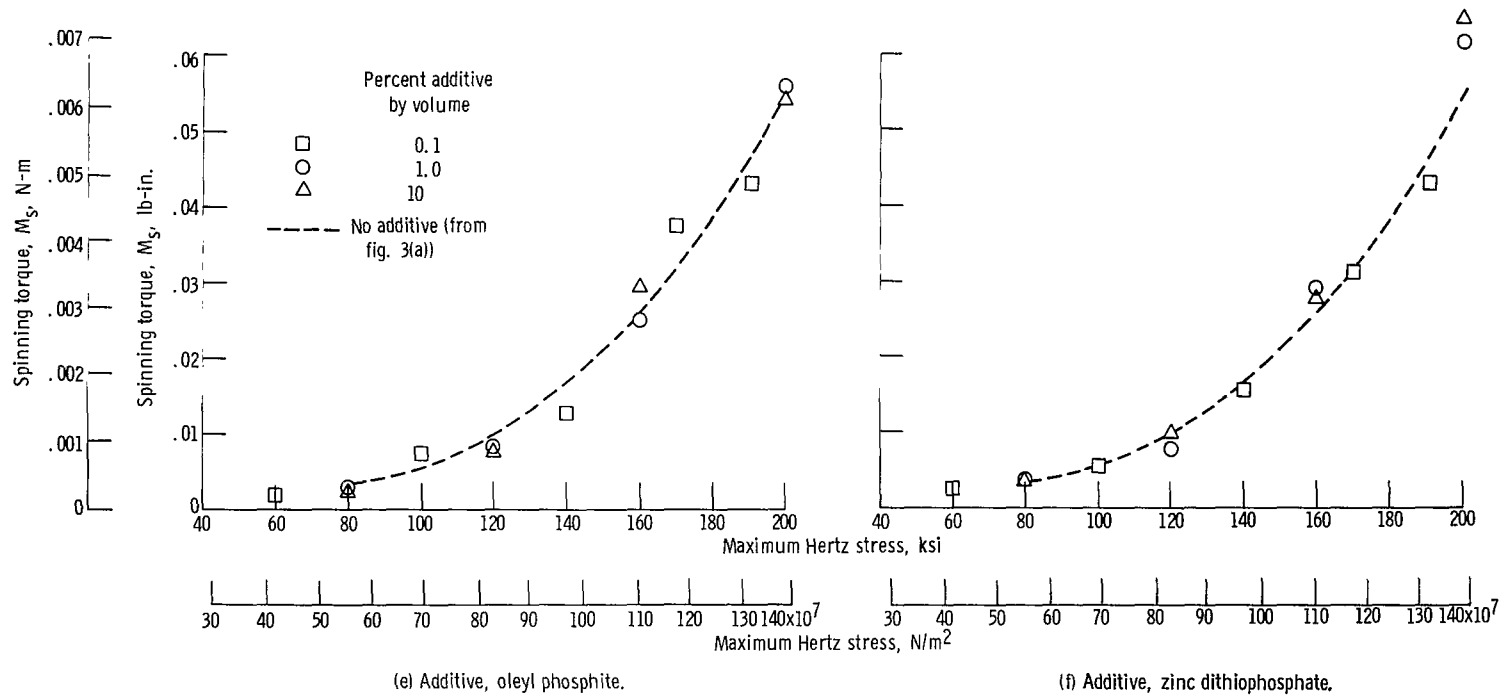


Figure 3. - Concluded.

under similar conditions and reported in references 10 and 11. These data show increasing spinning torque with increasing Hertz stress. The rate and magnitude of this increase can be predicted based on elastohydrodynamic (EHD) theory (ref. 9).

The theory of reference 9 assumed that a fluid film existed in the center of the contact region. According to conventional EHD theory, a film cannot be formed in the center of an elliptical contact where spinning occurs without rolling. However, examination of the specimens after running showed little or no surface damage and, hence, a lack of asperity contact. It is speculated that a lubricant film was formed due either to a "squeeze film" effect or to microasperity elastohydrodynamic lubrication. If the supposition of the existence of a film in the center of contact is incorrect, then the torque characteristics would be different from that of figure 3(a) because of metal to metal contact. It is also possible that, where an EHD film exists within the entire contact region, the torque characteristics shown in figure 3(a) for a ball spinning within a nonconforming groove can be changed. The additives may change the viscoelastic properties of the lubricant. As a result, the lubricant may become more shear sensitive; that is, the EHD film thickness would decrease with increasing shear rate. Torque is inversely proportional to film thickness. Hence, if the additive were to affect the viscoelastic behavior of the lubricant, a change in torque from that presented in figure 3(a) could be expected.

Tests were conducted with the synthetic paraffinic lubricant containing varying percentages of stearic acid. The results of these tests are presented in figure 3(b). The broken line is the curve from figure 3(a) for the synthetic paraffinic oil without the additive. The results for the stearic acid indicate that there is no effect of the additive on the resultant torque. This result suggests that there exists a complete elastohydrodynamic (EHD) film throughout the contact area and that the lubricant viscoelastic properties are not affected by the additive.

Test results with the oleic acid additive are shown in figure 3(c). These results are substantially the same as those for the stearic acid. Again there was no effect of the additive. This again indicates EHD lubrication with no effect on the viscoelastic behavior of the lubricant.

The results with the oleyl phosphate, oleyl phosphite, and zinc dithiophosphate additives, which are shown in figures 3(d) to (f), were the same as those for the previous two additives. No significant change occurred in torque due to the addition or amount of additive contained in the synthetic paraffinic oil.

Considerable data exists (refs. 1 to 6, and 12) on sliding friction which show a decrease in the friction coefficient for steel on steel with the additives used in this program. Because of these data, one might expect the spinning torque to be lower when evaluating these same additives. The reason that there is no change in the spinning torque with the addition of the additives can be explained by the supposition that there is a complete separation of the metal surfaces by the elastohydrodynamic film.

A typical grooved test specimen that ran with a smooth low torque value did not show evidence of gross metal to metal contact but had a slightly smoother surface where the contact ellipse was located. This type of surface and the torque trace indicate, as previously discussed, the existence of an elastohydrodynamic film over the complete contact ellipse.

When, because of lubricant side leakage and shearing of the lubricant, the torque trace became erratic and higher than normal, metal contact had occurred. It was found that very often the first contact between the spinning ball and the groove occurred at the edge of the inscribed circle within the contact ellipse (see fig. 4).

The reason the first metal to metal contact occurs more often at the edge of the circle and not at the center of the contact ellipse or elsewhere can be explained as follows. Upon loading the ball onto the groove the oil is trapped in the contact zone. The Hertzian

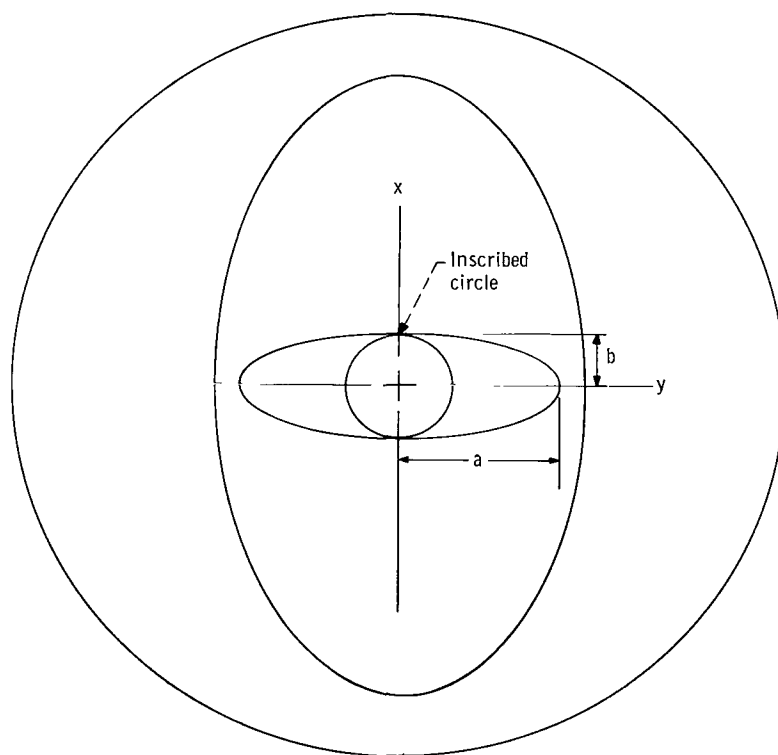


Figure 4. - Contact ellipse for ball in nonconforming groove (see fig. 2).

pressure, being higher at the contact center, causes a higher viscosity due to pressure to exist with a resulting thicker "squeeze film" at the center. Upon rotation, a film is maintained in the area outside the inscribed circle by hydrodynamic action. The greatest shear rate occurs in the "squeeze film" in the inscribed circle at the edge of the circle. As a result, the first film breakthrough occurs at that location.

Since the ball is spinning on a thin EHD film, the spinning torque is dependent on the rheological properties of the lubricant. Because the spinning torque was unchanged by the addition of the additives to the lubricant, it can be concluded that the rheological properties of the lubricant were unchanged by the additives.

SUMMARY OF RESULTS

The NASA spinning torque apparatus was used to conduct tests with SAE 52100 steel 1/2-inch (12.7-mm) diameter balls spun against nonconforming groove specimens with a conformity of 55 percent. The lubricant was a synthetic paraffinic oil to which was added 0.1, 1.0, or 10 volume percent an antiwear or extreme pressure (EP) additive. The additives used were stearic acid, oleic acid, oleyl phosphate, oleyl phosphite, and zinc dithiophosphate. Test conditions were as follows: a maximum Hertz stress of 60 000 to 200 000 psi (41×10^7 to 138×10^7 N/m²); a spinning speed of 1000 rpm; and room temperature (no heat added). Spinning torques were measured and the following results were obtained:

1. Under the test conditions, elastohydrodynamic conditions prevailed with no significant surface interaction.
2. The addition of the antiwear and EP additives in various concentrations to the synthetic paraffinic oil did not change the spinning torque over that obtained with the base fluid.
3. The viscoelastic properties of the base fluid were not changed by the additives tested.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 25, 1970,
126-15.

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